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(54) **TITLE OF THE INVENTION:**
MOS field-effect transistor and a method of manufacturing the same

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SPECIFICATION

1. TITLE OF THE INVENTION

MOS field-effect transistor and a method of manufacturing the same.

2. CLAIMS

What is claimed is:

1. An MOS field-effect transistor wherein the gate oxide film has halogen atoms and silicon atoms bonded thereto at least near the drain region.

2. A method of fabricating an MOS field-effect transistor, comprising a heat-treatment step performed after a gate electrode has been formed and in an environment containing halogen.

3. DETAILED DESCRIPTION OF THE INVENTION

Technical Field of the Invention

The present invention relates to the metal oxide semiconductor (MOS) field-effect transistor, wherein the deterioration of its operating characteristics due to hot electrons is prevented, and to a method of fabricating the same.

Description of Related Art

The existing MOS field-effect transistor and a method of fabricating the same are shown in Fig. 2, where 1 is a silicon substrate, 2 an element isolation region, 3 a gate oxide film, 4 a polycrystalline silicone layer, 5 a tungsten silicide layer, 6 a gate electrode, 7 a near-interface silicon atom, 8 a source region, 9 a drain region, 10 an interlayer insulating film, 11 aluminum interconnect, 12 a section removed by etching and 13 a contact hole.

MOS field-effect transistors are manufactured using steps A, B, and C illustrated in Fig. 2. The method of manufacturing and constitution of the MOS field-effect transistor will be described hereinafter with reference to these steps.

(1) Step illustrated in Fig. 2A

Firstly, the interlayer insulating film* 2 [sic] and the gate oxide film 3 are formed on the silicon substrate 1. The polycrystalline silicon layer 4 and the tungsten silicide layer 5 are then formed thereon.

This is followed by the removal, by etching, of the unneeded parts of the polycrystalline silicon layer 4 and the tungsten silicide layer 5, leaving the unaffected part as the gate electrode 6. The small "x"s shown inside the gate oxide film 3 in the diagram represent the near-interface silicon atoms 7.

The near-interface silicon atoms 7 are silicon atoms that have dangling bonds (bonding pairs that do not have partners). The types of silicon-atom terminal are shown in Fig. 3, and the near-interface silicon atom 7 is shown in Fig. 3A.

(2) Step illustrated in Fig. 2B

The source region 8, the drain region 9, the interlayer insulating film 10, the contact hole 13 and the aluminum interconnect 11 are formed according to publicly known methods.

(3) Step illustrated in Fig. 2C

The element is subjected to heat treatment (hydrogen annealing) at a temperature of 450°C in a hydrogen-gas environment. As a result, hydrogen becomes bonded to the near-interface silicon atoms 7 to become hydrogen-terminated silicon atoms 14. In the diagram, they are shown by small circles (○).

The reason for performing such hydrogen annealing will be described next.

Because the near-interface silicon atoms 7 lack bonding partners, they are charged. In other words, they are in an active state electrically. If they were to remain in the gate oxide film 3, then they would cause the scattering of the electron flow, thus causing the deterioration of the operating characteristics when the finished MOS field-effect transistor is used. For instance, they can cause changes to the threshold-level voltage, a decline in the speed of the transistor's performance or a decrease in the driving current.

For this reason, dangling bonds are terminated by bonding them with hydrogen. In other words, they are turned into the hydrogen-terminated silicon atoms 14. This eliminates the aforementioned electric charge, thus rendering them electrically inactive. The hydrogen-terminated silicon atom 14 is shown in Fig. 3B.

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* Translator's note: Probably "element isolation region 2" is intended.

A surface protecting film is then formed using a publicly known vapor deposition method under normal pressure. This completes the manufacturing process.

Problems to be Solved by the Invention

Problems:

The MOS field-effect transistor that is fabricated according to the aforementioned existing manufacturing method poses a problem in that the hydrogen-terminated silicon atoms 14 are readily changed back to the interface state by hot electrons that are generated while the transistor is in operation, and this causes a deterioration in the operating characteristics (i.e., low tolerance to hot electrons).

Description of the Problems:

It is well known that, when the MOS field-effect transistor is in use, a region of high electric-field density is created in the area from the lower part of the gate electrode 6 to the drain region 9 and that accelerated high-energy electrons (hot electrons, e_h) are produced in this high electric field.

These hot electrons react with the hydrogen-terminated silicon atoms 14 and hydrogen (H_2), which remains in the gate oxide film 3 as a result of hydrogen annealing, in the manner described by the following equation, where (2 Si - H) represents the hydrogen-terminated silicon atom 14 and (2 Si -) the near-interface silicon atom 7.

$$
\begin{aligned}
&(2\,\mathrm{Si}-\mathrm{H}) + \mathrm{H_2} + e_h \\
&\quad \rightarrow (2\,\mathrm{Si}-\mathrm{H}) + 2\,\mathrm{H} \\
&\qquad \rightarrow (2\,\mathrm{Si}-) + 2\,\mathrm{H_2}
\end{aligned}
$$

As a result of this reaction, the hydrogen-terminated silicon atoms 14 are turned back into the near-interface silicon atoms 7. This causes the deterioration of the operating characteristics of the MOS field-effect transistor. For instance, it could cause changes in the threshold voltage, or a reduction in the speed of the transistor's performance or in the driving current.

Means for Solving the Problems

In order to resolve the problems discussed above, the MOS field-effect transistor of the present invention is provided with silicon atoms that are bonded with hydrogen atoms in the gate oxide film, at least in the vicinity of the drain region.

Moreover, the method of manufacturing such an MOS field-effect transistor includes a heat treatment step carried out in an environment containing halogen and after the gate electrode has been formed.

Operation

During the manufacturing of the MOS field-effect transistor, near-interface silicon atoms that are produced in the gate oxide film when the gate electrode is formed are terminated by having them bond with halogen atoms of a high bond strength. Silicon atoms rendered into this form will not cause a decline in the transistor's operating characteristics because they will not be changed back to the interface state.

Moreover, during the fabrication of the MOS field-effect transistor, the application of heat treatment in an environment containing halogen carried out after the formation of the gate electrode makes it possible for the halogen to be diffused into the gate oxide film and to be bonded with the near-interface silicon atoms.

Description of the Preferred Embodiments

A preferred embodiment of the present invention will be described in detail hereinafter with reference to the accompanying diagrams.

Fig. 1 illustrates the MOS field-effect transistor of the present invention and a method of manufacturing the same. The symbols appearing in this diagram correspond to those of Fig. 2, and 15 represents a chlorine-terminated silicon atom.

Because the method of manufacturing the MOS field-effect transistor of the present invention follows the steps A, B, C and D illustrated in Fig. 1, the manufacturing method and constitution are described by following these steps.

(1) Step shown in Fig. 1A

After an element isolation region 2 and a gate oxide film 3 are formed on a silicon substrate 1 according to a publicly known method, a polycrystalline silicon layer 4 is deposited on the surface to a thickness in the order of 2,000 Å using the vapor deposition method under normal pressure.

Phosphorus (P) is then introduced by applying a heat treatment at 950°C for about 10 minutes in a $POCl_3$-gas environment. This is followed by the deposition of a tungsten silicide layer 5 to a thickness in the order of 2,000 Å using the sputtering method.

At the stage of the completion of this step, near-interface silicon atoms 7 are present in the gate oxide film 3.

(2) Step shown in Fig. 1B

A gate electrode 6 is formed by unneeded portions of the polycrystalline silicon layer 4 and the tungsten silicide layer 5 according to publicly known photo-lithography and dry-etching techniques.

(3) Step shown in Fig. 1C

Heat treatment is applied for about 60 minutes in an environment comprised of a gaseous mixture of chlorine gas (Cl_2), oxygen (O_2) and nitrogen (N_2).

This heat treatment allows the chlorine to penetrate through the top surface of the gate oxide film 3, which is located on both sides of the gate electrode 6, and diffuse into the gate oxide film 3. The chlorine then bonds with near-interface silicon atoms 7 present in the vicinity of the boundary between the gate oxide film 3 and the silicone substrate 1. As a result, the dangling bonds of the silicon atoms become terminated by chlorine to yield chlorine-terminated silicon atoms 15. They are indicated by small triangles (△) in Fig. 1, and one is shown in Fig. 3C.

However, because chlorine's velocity of diffusion in the gate oxide film 3 is low, the near-interface silicon atoms 7 remain unaffected at the far regions of the gate oxide film 3 (i.e., the section right under the center of the gate electrode 6).

(4) Step shown in Fig. 1D

A source region 8, a drain region 9, an interlayer insulating film 10, contact holes 13 and aluminum interconnect 11 are formed according to publicly known methods.

Next, the resulting element is subjected to hydrogen annealing at 450°C for about 20 minutes. This causes the hydrogen to be diffused to reach the remaining near-interface silicon atoms 7, which are directly under the central part of the gate electrode 6, and to bond with them, and turn them into hydrogen-terminated silicon atoms 14. As a result, the few remaining near-interface silicon atoms 7 are also rendered inactive.

This is followed by a step for forming a surface protective film comprised of an Si oxide film according to a publicly known vapor deposition method under normal pressure.

When the MOS field-effect transistor is fabricated according to a method such as the one described above, the chlorine-terminated silicon atoms 15, not the hydrogen-terminated silicon atoms 14, are present in the gate oxide film 3 in the vicinity of the drain, the part that is affected by hot electrons.

Nevertheless, the strength of the bond between the chlorine atom (Cl) and the silicon atom (Si) is greater than that of the bond between the hydrogen atom (H) and the silicon atom (Si). Therefore, the chlorine-silicon bond is not broken by hot electrons.

In other words, bonding pairs have no electric charge because they remain terminated. Consequently, when the MOS field-effect transistor is operated, it prevents the scattering of leaked electrons, thus preventing the transistor's operating characteristics from deteriorating.

Moreover, chlorine (Cl) was used in the above example, because its bond strength with the silicon (Si) is greater than that of the bond with hydrogen (H). However, other elements may also be used so long as the bond strength of their bond with silicon is similar to that of their bond with chlorine. Elements that may be used for this purpose include other halogens (Group VII elements) such as fluorine (F_2), bromine (Br_2), and iodine (I_2).

As for the temperature, the duration and other conditions to be used for carrying out the diffusion, consideration must be given for each element to be used so as to allow it to be diffused into areas where there is a risk of near-interface silicon atoms 7 being produced by hot electrons.

As for the material that may be used to make the gate electrode, there are materials that readily cause the production of near-interface silicon atoms 7 in the gate oxide film when the gate electrode is formed, and there are others that do not. For instance, metals with high melting points such as silicide and polycide are materials that readily cause this generation. The manufacturing of the MOS field-effect transistor, wherein the gate electrode is formed using such a material, according to the method of the present invention makes it possible to substantially improve its tolerance to hot electrons.

Advantages of the Invention

As described above, the method of manufacturing an MOS field-effect transistor of the present invention makes it possible for the halogen to be diffused into the gate oxide film and be bonded with the near-interface silicon atoms.

Moreover, with the MOS field-effect transistor fabricated according to this method, the silicon atoms are not returned to the near-interface state even by hot electrons, because the bond between the halogen atom and the silicon atom is strong. Consequently, the transistor's operating characteristics do not deteriorate.

4. BRIEF DESCRIPTION OF THE DRAWINGS

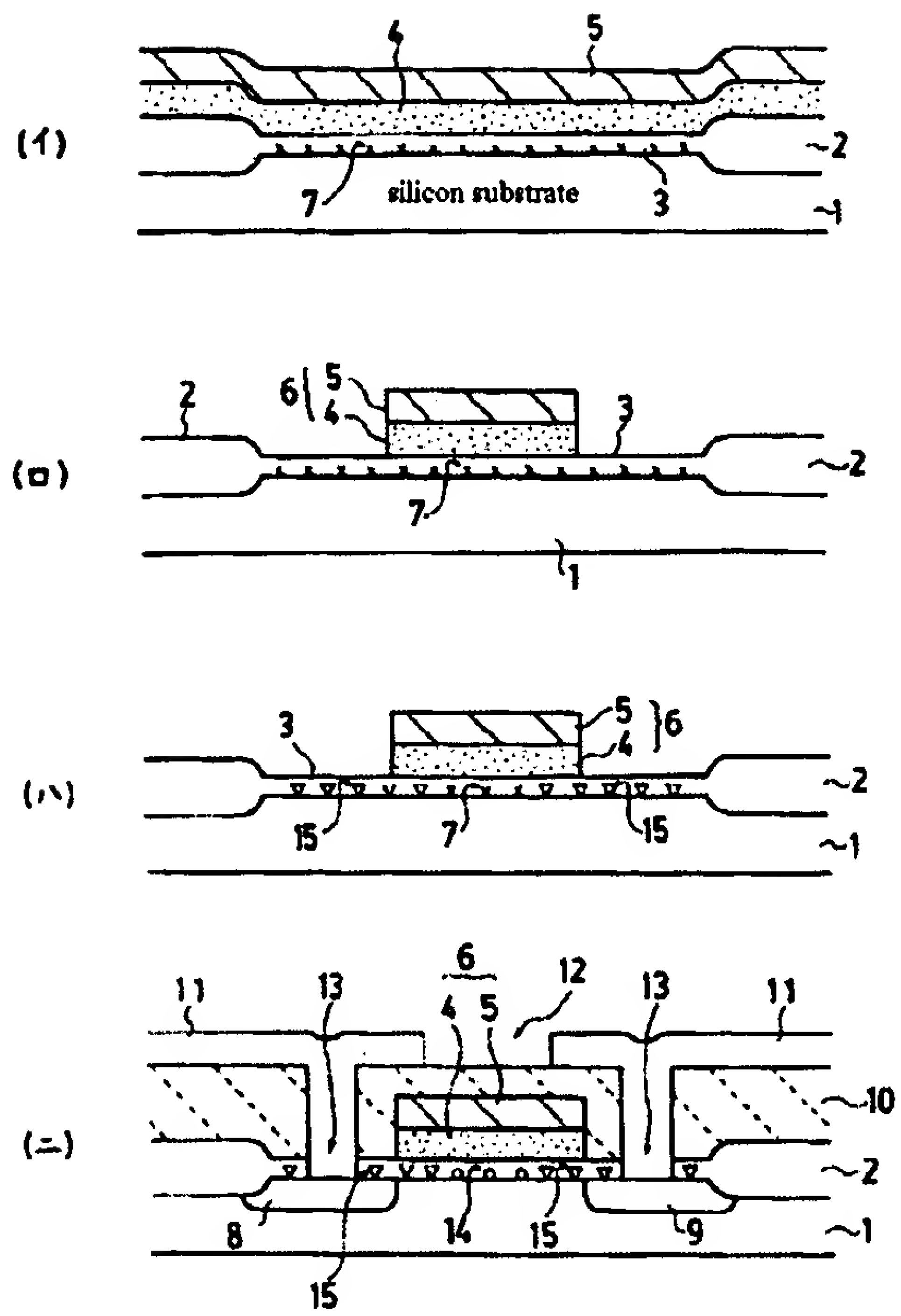
Fig. 1 shows a MOS field-effect transistor and a method of manufacturing the same according to the present invention.

Fig. 2 shows the conventional MOS field-effect transistor and a method of manufacturing the same.

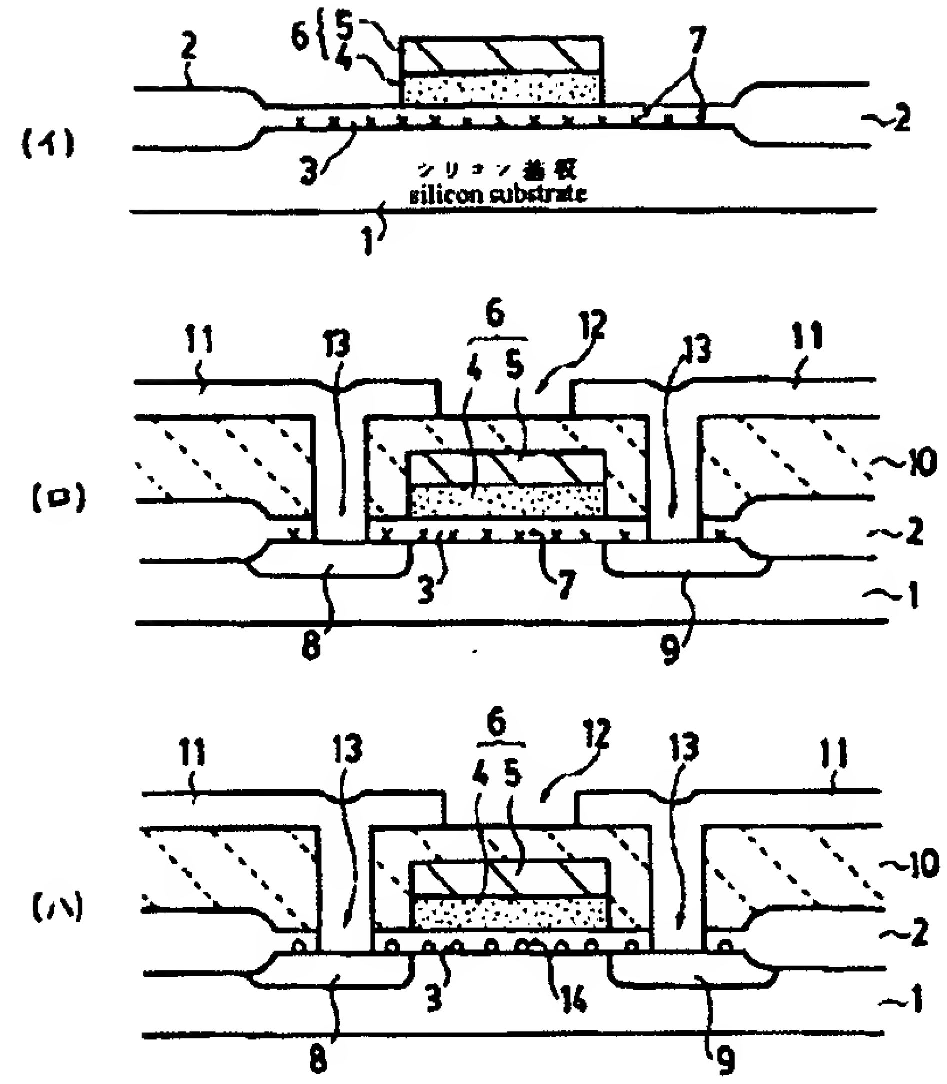
Fig. 3 shows the types of the terminal form of silicon atoms.

Description of the Reference Numerals

1: silicon substrate
2: element isolation region
3: gate oxide film
4: polycrystalline silicon layer
5: tungsten silicide layer
6: gate electrode
7: near-interface silicon atom
8: source region
9: drain region
10: interlayer insulating film
11: aluminum interconnect
12: section removed by etching
13: contact hole
14: hydrogen-terminated silicon atom
15: chlorine-terminated silicon atom



第 1 図



第 2 図

×	○	△
Si -	Si - H	Si - Cl
(イ)	(ロ)	(ハ)

第 3 図

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